Lateral Composition Modulation in InAs/GaSb Superlattices: Nanometer Sized Quantum Wires

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- The objective of this research is to understand the structural and optical properties of the nanowires formed by lateral composition modulation (LCM) in InAs/GaSb superlattices.

- A cross sectional scanning tunneling microscopy image shows the typical structure of the LCM (Fig. 1) where 100-150 nm InAs wire-like structures are formed which are a few to tens of microns in length (Fig. 2).

- X-ray diffraction reciprocal space maps (Fig. 3) were used to determine the LCM wavelength and composition and strain state of the layers. Cross contamination of As and Sb into the GaSb and InAs layers, respectively, alters the strain state of the layers which is directly related to the formation of the LCM.

- The optical properties of the material are altered as indicated by the absence of signature transitions in the absorption spectra (Fig. 4). This is critical in employing this system for optoelectronic device applications.

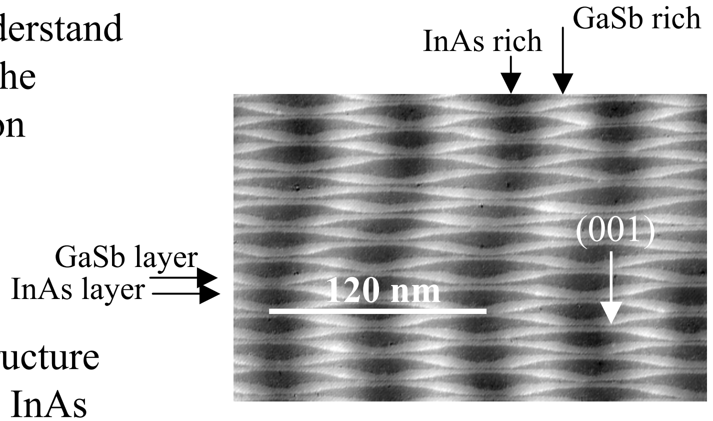

Fig. 1. XSTM image of the typical structure of LCM in an InAs/GaSb superlattice.

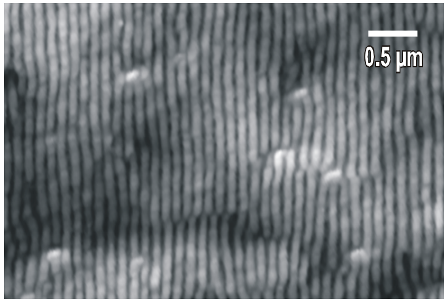

Fig. 2. AFM image demonstrating the formation of nanowire structures.

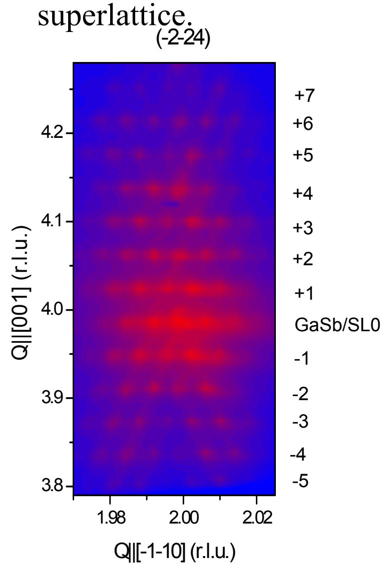

Fig. 3. XRD reciprocal space map of LCM sample.

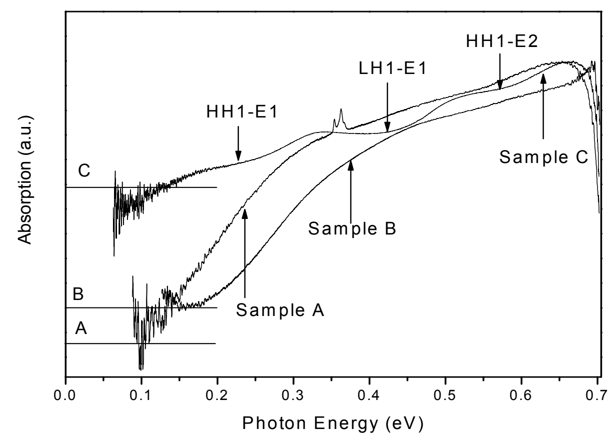

Fig. 4. Room temperature absorption of structures with (A and B) and without (C) LCM.

Research objective:

InAs/GaSb superlattices possess the unique type-II band alignment which gives the system an optical bandgap from 3 – 30 microns making it an interesting candidates for mid to far infrared detectors and lasers. To realize such devices, a complete understanding of the structural and optical properties of the system is necessary. The objective of this research is to understand the structural and optical properties of the nanowires formed by lateral composition modulation (LCM) in the InAs/GaSb superlattices.

Research results:

Several 140 period InAs/GaSb superlattice, each bi-layer nominally 40 angstroms thick, with InSb like interfacial bonds have been analyzed by cross sectional scanning tunneling microscopy (XSTM), x-ray diffraction (XRD), atomic force microscopy (AFM) and optical absorption. An X STM image of a typical structure, Fig. 1, shows that thickness undulations in the InAs layers, horizontal dark layers, are more pronounced than modulations in the GaSb layer, horizontal bright layers. This results in LCM along the lateral direction as is seen by the InAs rich (vertical dark) and GaSb rich (light regions) regions in Fig. 1. The bowing in the layers occurs due to strain and leads to the contrast in the XSTM image. InAs nanowires 120 – 150 nm in width and extending from a few to tens of microns in length are formed, Fig. 2. The wire are stacked in an out-of-phase manner which is directly related to the formation of the LCM.

XRD reciprocal space map (RSM) were performed to confirm the presence of the LCM yielding both the structure in the vertical (growth direction) and lateral direction (along the layers), Fig. 3. The pattern in reciprocal space mimics the out-of-phase stacking of the nanowires as seen in the real space STM image. Fits to the RSM data and additional XRD line scans yields the lattice constant, composition and strain state of the layers. Cross contamination of As and Sb into the GaSb and InAs layers, respectively lead to an alteration of the strain state of the layers. Our research has shown that the cross contamination of the group V anions along with the InSb interfacial bond type are crucial for nanowire formation. We have also shown that the optical response of the structure is altered by the presence of LCM as can be seen in the absence of signature transitions in the room temperature absorption spectra of two samples with and one without LCM, Fig. 4.

Significance of this research:

The presence of LCM in InAs/GaSb superlattices will have a significant impact on performance of devices utilizing this system. The key to utilizing these structures is to completely understand the formation of the nanowire as well as their optical. response. Through this research we have determine that the InAs nanowire array resulting from LCM does affects the optical response of the structures. However, by controlling the dimensions and composition of the nanowires, this system may be utilized to enhance the performance of current devices or may be employed to develop new devices based on quantum confinement in the the InAs nanowires.

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Education and Outreach:

▪During the spring semester a special topics course entitled “Experimental Techniques in Solid State Physics” was offered. This course entailed the collaboration of two graduate students (Julia Wickett and Priya Chinta) and one undergraduate (Carol Voight) where various techniques for structural, electrical and optical characterization of semiconductors were explored. We also participated as judges for the Houston Engineering and Science Fair in Houston, Texas.

The PI lectures on nanotechnology and it’s importance to our future to 8^{th} grade students at the Detroit Academy for Science, Math and Technology in Detroit, Michigan.

▪As part of a Martin Luther King Visiting Professor at Wayne State University, the PI spoke to a 7^{th} and 8^{th} grade science class at the Detroit Academy for Science, Mathematics and Technology. Several of those students and their teacher attended a technical colloquium which was presented to the Department of Physics at Wayne State University.